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Six-Year Growth of *Eucalyptus Saligna* Plantings as Affected by Nitrogen and Phosphorus Fertilizer

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IN BRIEF...

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Retrieval Terms: Eucalyptus saligna, Hawaii, fertilizer, nitrogen, phosphorus, biomass

Growth responses of *Eucalyptus saligna* to nitrogen (N) and phosphorus (P) fertilizers were assessed in bioenergy plantations on abandoned sugarcane land in Hawaii. Fertilizers were applied three times (0, 6, and 15 months after planting) in a factorial design with four dosages each of N (0, 25, 50, and 75 g urea per tree) and P (0, 30, 60, and 90 g triple superphosphate per tree). Phosphorus and the N x P interaction had little effect on tree growth beyond the first few months. Effects of N, however, were dramatic during the first year, and benefits were sustained through 6 years—the projected rotation age for bioenergy crops of Eucalyptus in Hawaii. Trees treated with 25 g urea were twice as tall, twice as large in diameter, and produced four times as much biomass per ha as untreated trees. Compared with trees treated with 25 g urea, trees treated with 50 g and 75 g urea were 35 to 45 percent larger in diameter and height and produced twice as much biomass per ha. Effects of N on height growth and diameter growth dropped markedly during the third year and were no longer statistically significant during the fifth and sixth years. Survival of the trees was also affected by N fertilizer. At 6 years, only 61 percent of the untreated trees survived compared with 92 to 94 percent survival for N-fertilized trees. In addition, N fertilizer increased uniformity of tree size within the stand. This uniformity may result in improved efficiency and lower costs of harvesting and processing. Bioenergy plantations of *E. saligna* established on abandoned caneland with similar site and soil characteristics will benefit from high dosages of N fertilizer and presumably from applications repeated every 6 to 12 months.

INTRODUCTION

In 1979, the BioEnergy Development Corporation (a subsidiary of C. Brewer and Company, Ltd.) and the Pacific Southwest Forest and Range Experiment Station began to develop silvicultural information for growing bioenergy plantations of *Eucalyptus saligna* (Sm.) and other *Eucalyptus* spp. in Hawaii. This research effort is part of, and is funded by, the Short Rotation Woody Crops Program of the U.S. Department of Energy. Studies included spacing trials, fertilization tests, species comparisons, and provenance or progeny evaluations. Previous work in Hawaii suggested that fertilization would be needed to attain high yields (Qureshi 1978) and that the nutrients most likely to limit growth were nitrogen (N) and phosphorus (P).

Fertilization and nutritional studies of *Eucalyptus* spp. in Australia and Brazil also pointed to a general need for supplementary N, and sometimes P, especially at planting or soon thereafter (e.g., Cromer 1971, Cremer and others 1978, Knudsen and others 1970). An exception was failure of N to induce significant response in *E. grandis* (Hill ex Maid.) planted on a South African site previously occupied by a nitrogen-fixing *Acacia* species (Pennefather and MacGillivray 1970).

We therefore designed a study to examine effects of four dosages of N and P, applied in a factorial arrangement, on survival and growth of *E. saligna*. The treatments were applied at 0, 6, and 15 months after planting on the major soil available for *Eucalyptus* plantings. Early effects on tree growth and nutrient status are reported elsewhere (Yost et al., submitted).

This paper reports information on tree growth and stand development through age 72 months, which is at present the projected rotation age for bioenergy crops of *E. saligna* in Hawaii.

STUDY AREA

The study was established about 20 km north of Hilo (19° 30'N, 155° 15'W) on the island of Hawaii. This area is typical of much marginal and abandoned sugarcane land along this Hamakua Coast.

Elevation of the planting site is about 480 m, and annual rainfall averages 5000 mm, distributed fairly evenly throughout the year.

Slope is less than 10 percent. The soil series is Akaka silty clay loam (thixotropic isomesic Typic Hydrandept) and is medium acid (pH 5.7 to 6.0). Usually, this soil is very strongly acid (<pH 5.0), but 4.5 tonnes per ha of crushed coral (92 pct calcium carbonate) had been added to the site about 1 year before the *Eucalyptus* trees were planted. Total N concentration in the surface soil averaged 0.4 percent, similar to or slightly lower than that of most other soils along the Hamakua Coast. Extractable P (Truog 1930), exchangeable potassium (K), and exchangeable magnesium were also low at 7, 40, and 40 ppm, respectively. Amounts of exchangeable calcium were unusually high (>800 ppm in the subsoil) because of the previously mentioned application of crushed coral.

Sugarcane was produced on the land for more than 50 years, but production was abandoned in the mid-1970's because of low yields. The site was then prepared for taro production by clearing and applying of crushed coral, but taro was never planted. Immediately before our study, various grasses and broad-leaved weeds common to the Hamakua Coast grew in the area. The site was prepared for *Eucalyptus* by disk harrowing. Redeveloping vegetation was sprayed with glyphosate[1] before planting in 1979.

METHODS

The experiment is a randomized complete block design with four replications of 16 fertilizer treatments, four dosages each of N and P in a factorial arrangement. Three-month-old containerized seedlings of *E. saligna* were planted in July 1979 at 1.5 m by 1.5 m spacing (4444 trees per ha). Individual plots were 182 m^2 and consisted of 81 trees. Weeds were controlled during the first year by sickling and one broadcast application of dalapon[1] at 4.7 kg per ha of active ingredient.

Nitrogen fertilizer was applied as agricultural grade urea (0, 25, 50, and 75 g per tree per application), and phosphorus fertilizer was applied as triple superphosphate (0, 30, 60, and 90 g per tree per application). A uniform dosage of K (30 g of muriate of potash) was also applied to each tree. All fertilizers were placed in a hole 15 cm away from the tree at time of planting, at 6 months, and at 15 months. Subsurface applications were used to minimize potential losses in runoff and erosion during heavy storms, which are common in this high rainfall area. Summed for the three applications, the fertilizer dosages were equivalent to the following amounts per ha:

N at 0, 150, 300, and 450 kg N per ha
P at 0, 75, 150, and 225 kg P per ha
K at 200 kg K per ha

[1]This publication does not contain recommendations for pesticide uses reported, nor does it imply that they have been registered by the appropriate government agencies.

Diameter and height measurements used in this paper were taken on the inner 25 trees in each plot at 12-month intervals through 72 months. Mean diameter and height were calculated for each plot, and periodic increments for these variables were calculated as differences between the means for two periods. Height and diameter data were examined for differences among treatments at each measurement date by standard analyses of variance. When treatments were significantly different, means were separated by Duncan's Multiple Range Test at $P \leq 0.05$.

Survival was calculated as percentage of live trees remaining on the inner plot at each measurement. Tree biomass (total above ground dry matter, including foliage) of each measured tree was estimated by the equation:

$$\log_e \text{Dry Weight} = -3.8604 + 0.9644 \log_e (\text{Diameter}^2 \times \text{Height}).$$

This equation was developed from trees of comparable age and size

$$(n = 93,\ R^2 = 0.99,\ \text{RMSE} = 0.11).^2$$

Weights of all measured trees on each plot were summed and averaged. Mean tree weights were then multiplied by number of surviving trees per ha to provide estimates of dry biomass per ha. Effects of fertilizer treatment on stand differentiation were estimated by the coefficient of variation of individual tree heights and diameters in each plot.

RESULTS AND DISCUSSION

Effects of Fertilizer Treatments on Individual Tree Growth

Phosphorus affected tree growth only in the first few months after planting. Although a trend of increased height with increased dosage was present at the end of the first year (*fig. 1*), differences were not significant ($p = 0.09$). Beyond 12 months, the trend disappeared. The N x P interaction was significant for height and diameter at 12 months, but not for the height and diameter increments that occurred during the 9 to 12 months before the measurements were taken. Thus, the significant N x P interaction was essentially a carry-over effect from early size differences. Such lack of response to P was surprising in view of the low levels of extractable P in the soil prior to treatment and findings of responses by *E. saligna* to P fertilizers in other Hamakua Coast soils (Qureshi 1978).

At least two factors may be involved in this failure of P to stimulate growth beyond the first few months in our study. One factor is the high P fixation potential of the Akaka soil series (Fox and Searle 1978). The amounts of P added may have been altered so rapidly into unavailable compounds that little of the fertilizer P was available and taken up by the trees. A second possibility is that extractable P values for this soil do not accurately reflect amounts of P available to *E. saligna* root systems. Other research has demonstrated that eucalypts can utilize insoluble phosphates (Mullette and others 1974). Thus, after the trees became established and mycorrhizal associations developed, the root systems may have been able to tap large amounts of insoluble phosphates remaining from repeated applications of P fertilizer while the site was in sugarcane production.

Response to N fertilizer, on the other hand, was dramatic during the first year (*fig. 1*) and benefits were sustained for several years (*table 1*). Growth was extremely poor in plots receiving no N; trees receiving the lowest dosage of N fertilizer (25 g urea) were at least twice as tall and twice as large in diameter from age 12 to 72 months. Initial differences between the lowest N treatment (25 g urea) and the two higher N dosages were equally great.

Such differences remained substantial at 72 months, but trees receiving the two highest dosages of N reversed performance (*table 1*). At 36 months and thereafter, trees receiving 75 g urea averaged smaller than trees receiving only 50 g urea. This trend parallels a similar difference in foliar nitrogen status observed in samples collected at 9, 12, 18, and 24 months (Yost and others, in prep.). At 9 and 12 months, foliar N concentration was highest in the 75-g urea treatment; at 18 and 24 months, it was highest in the 50-g urea treatment. Apparently, the fertilizer treatment applied at 15 months was not taken up in proportion to dosage—at least not for the highest two dosages.

Although benefits from the N treatments remained through 72 months, effects on incremental growth dropped markedly during the third year and continued to diminish through the sixth year (*figs. 2a and b*). Effects of N treatment on periodic height and diameter growth during the fifth and sixth year were no longer statistically significant.

The dramatic growth response of *E. saligna* to N in this soil as well as the rapid drop in growth after the 15-month application suggest that frequent N amendments may be required to maintain growth rates. This situation is probably related to the mineralogy of the Akaka soil series. Although the series is relatively high in total N, most of the N occurs in unavailable, stable compounds formed in association with the amorphous clay minerals so abundant in such soils (Fox 1980, Uehara and Gillman 1980). Because of the tendency to form such stable complexes, recycling of N to the trees following litterfall is probably rather low. Moreover, the high intensity and frequent rainfall at the site undoubtedly results in downward leaching of large amounts of the N that is readily mineralized. Short-rotation *Eucalyptus* plantations on these soils, therefore, are likely to require repeated applications of N fertilizer, perhaps at 6- to 12-month intervals, if optimum yields are to be achieved.

Effects of Fertilizer Treatments on Stand Development

Phosphorus treatments had no effect on tree survival or on growth beyond the first year, and therefore had essentially no effect on stand development. Effects of N applications, on the other hand, were substantial. First-year survival averaged 98 percent and was excellent in all treatments, but there was a gradual attrition of trees in plots receiving no N (*fig. 3*). At 72 months,

Table 1—*Effect of various dosages of nitrogen fertilizer on height and diameter of* Eucalyptus saligna, *aged 12 to 72 months*[1]

Nitrogen dosage (g urea)	Age (months)					
	12	24	36	48	60	72
	Height (m)					
0	.83d	1.68c	2.89c	3.91c	4.53c	5.07c
25	1.96c	5.79b	7.94b	9.26b	10.14b	10.93b
50	3.48b	9.02a	11.87a	13.62a	14.68a	15.82a
75	4.27a	9.35a	11.42a	12.42a	13.38a	13.90a
LSD[2]	.38	.84	1.24	1.57	1.87	2.09
	Diameter (cm)					
0	—	.55c	1.41c	2.02c	2.39c	2.73c
25	.87c	3.95b	5.07b	5.86b	6.33b	6.64b
50	2.58b	6.02a	7.36a	8.62a	9.05a	9.49a
75	3.33a	6.47a	7.49a	8.39a	8.66a	8.92a
LSD	.40	.52	.72	.89	1.01	1.04

[1]Means within a column followed by the same letter do not differ significantly at the 5 percent level of probability.

[2] Least significant difference for comparing height and diameter differences among nitrogen treatments at various ages.

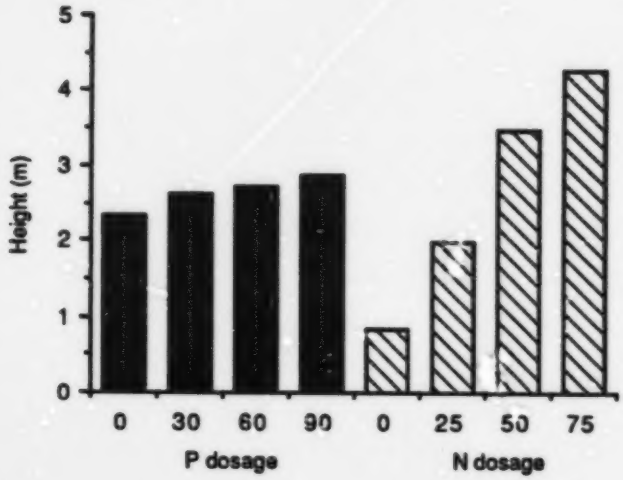
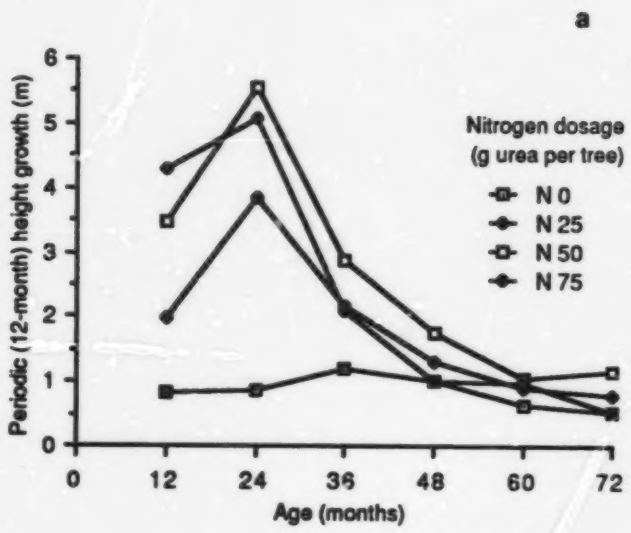


Figure 1—Height of *Eucalyptus saligna* at 12 months after planting as influenced by various dosages of nitrogen and phosphorus fertilizer.



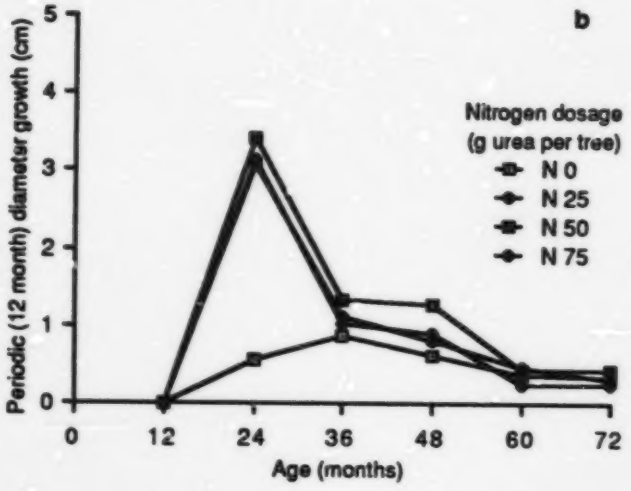


Figure 2—Trends in height growth (*a*) and diameter growth (*b*) as influenced by various dosages of nitrogen fertilizer.

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only 61 percent of the trees remained in the latter plots whereas survival of trees in plots receiving N fertilizer was 92 to 94 percent.

In addition to affecting survival and average tree size, N fertilizer treatments influenced uniformity of tree sizes within the plots. Stand uniformity was examined by calculating the coefficient of variation of periodic height and diameter measurements on each plot. Variation in height was similar in all fertilizer treatments at 12 months (*fig. 4a*). At subsequent ages, however, variation in both height and diameter was inversely related to N dosage (*figs. 4a and b*). Heights and diameters of trees receiving no N fertilizer were extremely variable; coefficients of variation for height and diameter ranged from 73 to 82 percent and 80 to 124 percent, respectively, from age 24 to 72 months. Variation was dramatically reduced with application of 25 g urea per tree. Additional reductions in variation occurred with application of the two higher N dosages, but there was little difference between the 50- and 75-g urea treatments, which parallels effects of these dosages on average tree growth. Increased stand uniformity has also been observed in fertilized plantations of *Pinus* and *Eucalyptus* in other tropical and subtropical areas (Evans 1980) and may lead to improved efficiency and lower costs of harvesting and processing, particularly in short-rotation forest crops.

Although differences in mean tree growth and survival among plots receiving various N dosages were substantial, the combination of these effects on growth and survival resulted in even greater differences in biomass yields per ha. Estimated total dry weight yields per ha at 48, 60, and 72 months showed differences of eight- to tenfold in yield between plots with no N and those receiving the two highest dosages (*table 2*). Moreover, estimated yields of the two higher dosages (50 and 75 g urea) were about double those of the lowest N dosage (25 g urea).

Clearly, N fertilizer not only is needed for adequate growth, but responses to high dosages (50 g urea per tree) are substantial. Had additional N been applied at 24 months and periodically thereafter, stand growth and differential responses to N dosages may have been even greater. Slightly younger *Eucalyptus* trees (65 months) grown in mixture with nitrogen-fixing *Albizia falcataria* (L.) Fosberg on the same soil type at a nearby site were 6 percent taller and 40 percent larger in diameter than those of the most effective treatment (50 g urea) in this study (DeBell and others 1985).

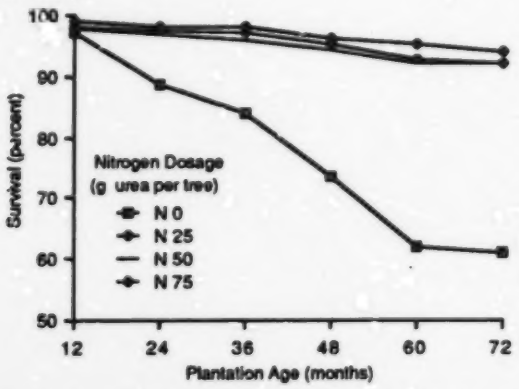
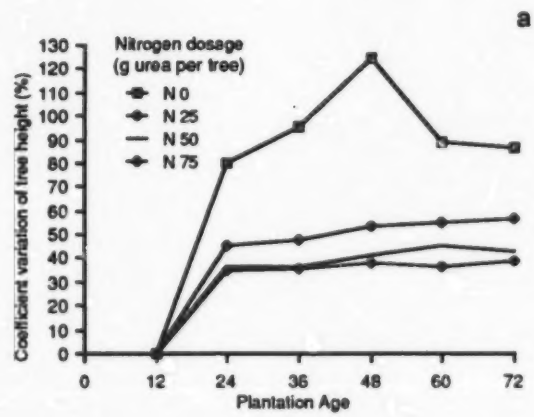


Figure 3—Survival of *Eucalyptus saligna* plantings to age 72 months as influenced by various dosages of nitrogen fertilizer.

Table 2—*Effect of various dosages of nitrogen fertilizer on stocking, mean tree biomass, and yield at 48, 60, and 72 months*

Age (mos.)	Nitrogen dosage	Stocking	Mean tree biomass	Estimated dry yield
	g urea/tree	*trees per ha*	*kg*	*tonnes per ha*
48	0	3266	2.91	9.50
	25	4233	9.37	39.66
	50	4188	22.54	94.40
	75	4277	19.84	84.86
60	0	2744	3.77	10.34
	25	4122	10.65	43.90
	50	4088	27.50	112.42
	75	4233	21.75	92.07
72	0	2711	4.83	13.09
	25	4088	14.45	59.07
	50	4088	33.41	136.58
	75	4177	23.97	100.12

[a]This value for root mean square error is in terms of the natural logarithm of biomass.



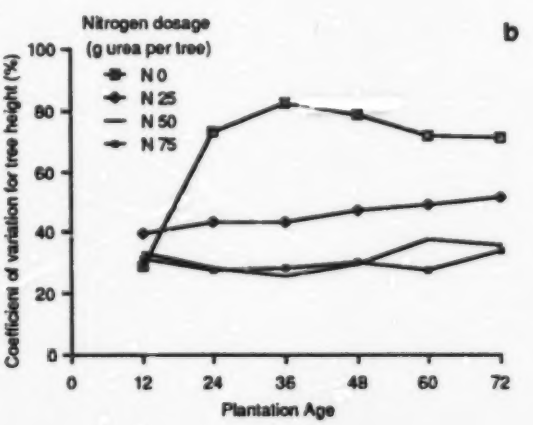


Figure 4—Variation in tree height (*a*) and diameter (*b*) as related to plantation age and nitrogen dosage.

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CONCLUSIONS

1. Phosphorus fertilizer dosages had no effect on tree survival and little effect on growth at this site beyond the first year.

2. Lack of N fertilizer resulted in poor growth and gradual mortality.

3. Tree size and survival were increased substantially by the lowest N dosage (25 g urea) and even more at higher dosages (50 and 75 g urea). Fertilizer effects on periodic growth diminished in the third year and thereafter; they were no longer significant in the fifth and sixth year.

4. Stand uniformity was greatly increased by applications of N fertilizer.

5. Estimated dry yield (above ground) at 72 months averaged 13, 59, 137, and 100 tonnes per ha for the 0-, 25-, 50-, and 75-g urea treatments, respectively. Mean annual production for the two highest N dosages averaged 20 dry tonnes per ha.

6. Bioenergy plantations of *E. saligna* established on abandoned caneland with similar site and soil characteristics will benefit from high dosages of N fertilizer and presumably from applications repeated every 6 to 12 months.

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Retrieval Terms: Eucalyptus saligna, Hawaii, fertilizer, nirogen, phosphorus, biomass